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Subject

SOME NEW DEVELOPMENTS AND PROPOSALS IN HIGH-ENERGY DETECTORS

In view of the expected increase in particle energies as a result of the 200-400 BeV proton accelerator presently under design, it would seem that our existing detection devices will not be adequate in many respects to cope with the much higher energy interactions involved. Certain modifications, of course, can be made to improve this. Even so, as indicated in Ref. 1, it would be extremely worthwhile to search for new methods of detecting, identifying, and measuring the energy of charged particles in the relativistic region so as to enable us to fully utilize the 200 BeV accelerator when it will be in operation in 1972 and to enable us to achieve better experimental results.

Detectors which have the ability to identify individual charged particles and to measure their momenta are not only important in their application in experiments directly involving them, but they would also be indispensible in serving as trigger devices for those other detection systems which do not possess the ability to identify and to select the desired particles for triggering. Examples of such devices are bubble chambers, streamer chambers, wire spark chambers, etc.

Some new developments in the detectors already discussed in Ref. 1 are listed below:

(i) <u>Transition Radiation from Relativistic Charged Particles</u>

Referring to Refs. 1 and 2, the radiated energy of transition radiation caused by a charged particle when traversing a boundary surface between a medium and vacuum or vacuum and a medium is given by

$$dW = \frac{e^2\beta^2 \cos^2\theta \sin^2\theta \left|\Sigma - 1\right|^2}{\pi^2 c (1 - \beta^2 \cos^2\theta)^2} \cdot \left| \frac{1 - \beta^2 \pm \beta\sigma}{(\epsilon \cos\theta + \sigma)(1 \pm \beta\sigma)} \right|^2 \cdot dr\,dw \ldots \quad (1)$$

where ϵ = ϵ (w) is the complex dielectric constant of the medium

B = v/c = velocity of the particle

θ = angle of observation with respect to the Z - axis;

$$\sigma = \sqrt{\epsilon - \sin^2\theta}$$

(-) sign applies for the medium-vacuum case or forward radiation

(+) sign applies for the vacuum-medium case or backward radiation.

The formula shown above is derived for normal incidence to the boundary surface. However, since the intensity of the transition radiation from a single boundary surface for each individual particle is extremely low, a large number of boundary surfaces in cascade would have to be employed in order to obtain sufficient transition radiation intensity for quantitative measurement.

If the above formula is integrated over the optical spectrum only (including the near ultra violet region), we find that the integrated transition radiation intensity is dependent on the incident-particle energy logarithmically in the relativistic region, i. e.,

$$W_{opt.} \propto \log E_{inc.} \tag{2}$$

In order to facilitate light collection, the foils used for the transition radiation detector are mounted at an angle of 60^{o} from the normal to the boundary surfaces. Thus, the radiation both in the forward and in the backward directions can be easily collected and measured separately if desired. The expression for the transition radiation at an oblique incidence is much more complicated than those for normal incidence as expressed in (1), but after integration over the optical spectrum we obtain the same logarithmic energy dependence as in (2).

Experimental verification of this effect has been obtained by using protons, pions and electrons over a wide range of γ 's

$$\gamma = \frac{1}{\sqrt{1 - \beta^2}} = \frac{E_{inc.}}{m_o c^2} . \tag{3}$$

The number of metal foils used in the detector was 118 and these foils were spaced uniformly over a total length of 8 inches. The efficiency obtained for such a counter is of the order of 2%.

When we integrate the transition radiation over the x-ray spectrum, we find that the integrated radiation energy is proportional directly to the incident particle energy in the relativistic region, i. e.

$$W_{x\text{-}ray} \propto E_{inc.}$$

This would provide a much better handle for energy determination and particle-identification purposes than the logarithmic dependence. Furthermore, since the absorption for x-rays in thin foils is small, normal incidence of the charged particles can be tolerated and the problem of collecting the transition radiation would be much simpler.

An x-ray transition radiation detector has been constructed and is being bench tested. The detector consists of a stack of thin metal foils whose normal is in the direction of the incident particle. No light funnels are needed in this case and the detector for the x-rays is a solid-state detector (either a Li-drifted germanium detector or a silicon detector). The solid-state detector is placed behind the foil stack directly in line with the normal to the foils. A deflection magnet is placed between the stack and the x-ray detector so as to deflect the beam particles away from the x-ray detector.

(ii) Surface-Plasma Oscillations

Surface-plasma oscillations in thin metal films have been detected by their radiation at optical frequencies from an optical-grating surface.[3]

On a flat surface the SPO (surface-plasma oscillations) do not radiate because the phase velocity in the surface is less than that of light. However, any surface roughness (such as a grating surface) allows the surface to impart certain additional momentum to the SPO so that it can couple to the radiating electromagnetic field. Thus, if a charged particle is incident normally upon the thin-grating foil, SPO is set up and radiations will be observed from the surface. The intensity of this radiation is found to be much stronger than the transition radiation although no quantitative data is yet available. So far as is known, no energy dependence of the SPO on the incident particle has been determined.

A stack of pressed optical-grating films are being assembled with appropriate light collecting funnels. Tests on the SPO radiation from individual charged particles as well as its energy dependence are being planned.

(iii) Secondary Emission Detector

As mentioned in Ref. 1, a special electron multiplier tube has been constructed by LaRadio Technique of France. It incorporates a low-density secondary emitter film as cathode which has a high-secondary emission efficiency of 2-5 at 1 BeV electron energy.* This tube is being tested in the AGS test beam using 3 BeV pions and protons. Preliminary results showed that the efficiency for the single secondary emitter film contained in this tube is of the order of 11% at 3 BeV energy. Experiments are in progress to determine whether there is any energy dependence effect of the secondary emission in such a thin film by

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* The secondary emitter was provided by E. Garwin and J. Edgecumbe of SLAC.

individual particles as a function of incident-particle energy.

In a recent paper by Bakhshyan and Garibyan a theoretical analysis has been made on the secondary electron-emission monitors in a case in which the primary particle is extremely relativistic. It was found that in the operation of the monitor an essential role is played by the oxide layer that forms on the surface of the emitter. If a strong electric field is created in that layer, the secondary emission current will be dependent on the energy of the primary particles.

It is already known that, for any fixed-incident particle energy, the low-density secondary emitter surface has to be charged in order to attain high efficiency in secondary emission. Therefore, it would be extremely interesting to ascertain the energy dependence effect of such a secondary emitter surface under different charged conditions.

(iv) Time of Flight Measurement with Picosecond Time Resolution (10^{-12} seconds)

As stated in Ref. 1, the time of flight differences taken by a proton, a kaon and a pion at 200 BeV/c and by light traversing a distance of 1 kilometer are 35.9, 9.7 and 0.7 picoseconds respectively. Thus, if we have means to provide picosecond time resolution, then it would be fairly easy to separate and identify charged particles at 200 BeV/c momentum.

There are two possible ways at the present thinking to achieve picosecond time resolution and the first one mentioned below looks particularly promising.

(1) Charge-Sensitive Electron Multiplier

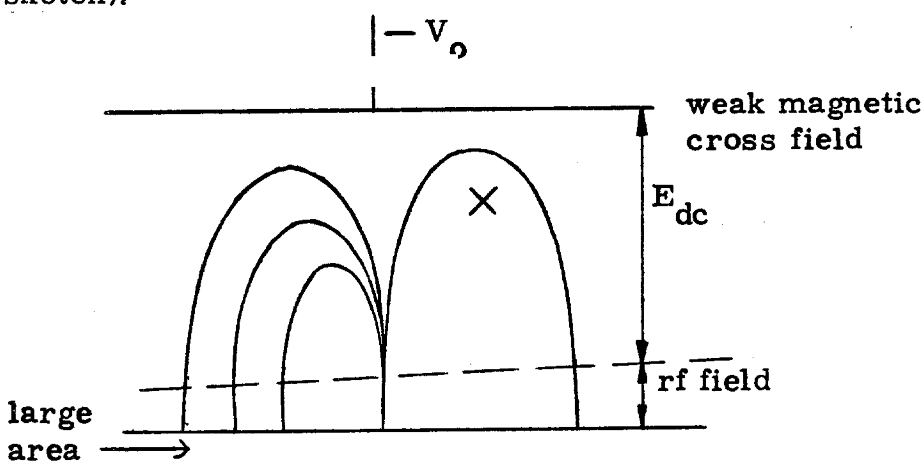
We have proposed to modify the present DCFP (dynamic-cross field-photomultiplier) system to convert it into a charge sensitive electron multiplier and to improve its present time resolution of ~ 10^{-10} second into ~ 10^{-12} second. Two separate steps of approach are being contemplated simultaneously:

(a) To replace the photo cathode by a low-density secondary emitter which will be extended to replace the ordinary secondary emitter for the first 4 or 5 loops of operation. This will enable the device to be sensitive to charged particles directly without having to go through photo conversions and also to achieve a loop gain of the order of 50 instead of 2 or 3 per loop. Thus, one can expect to achieve sufficient gain with 5 to 7 loops to yield an adequate output current. This is a small number of loops involved as compared with the 40 (mode II operation) to 80 loops used in the SLAC application.

Preparations are being planned to carry out the above mentioned modifications with the collaboration of E. Garwin at SLAC and tests will be made as soon as the modified-electron multiplier is completed. Particular attention will be paid to the general efficiency of the electron multiplier, time phase stability, the maximum time resolution obtainable and how well the gating capability is.

(b) To design a completely new electron-multiplier system so as to incorporate a much higher radio frequency, say a factor of 10 higher than the s-band frequency (3, 000 ı presently employed in the DCFP. An improvement in time resolution by at least a factor of 10 is expected. Further improvement in time resolution can be achieved by phase-gating techniques, etc.

As the radio frequency of the electron multiplier is raised higher the physical size of the charge-sensitive area at least in one dimension becomes smaller. In order to alleviate this difficulty, a rf free drift space can be provided above the cavity proper with the presence of only a dc electric field and a weak cross-magnetic field so as to allow an effective large electron loop be formed for a number of rf cycles (see sketch).



The above plans are being studied with the collaboration of O. L. Gaddy and D. F. Hokhauser of the University of Illinois.

(2) Time of Flight Measurement using Laser Light Pulses

The advancement in the application of fast laser light pulses has progressed very rapidly in the past few years. Laser light pulses of 10^{-12} sec in width can be produced either singly or repeatedly at a time interval up to 100 n sec.[5] The triggering of a laser light pulse involves too much energy and time and, therefore, any direct triggering by means of a single-charged particle would be impractical in the present state of the art. However, if a secondary medium through which the laser light passes and whose dielectric property can be changed due to the passage of a charged particle, then the phase of the laser light is shifted and the time of the shift can be detected. The question is what kind of secondary medium possesses the above-mentioned characteristics.

If we consider the case in a brutal force manner, the amount of charges required in a secondary medium to cause a detectable phase shift in a laser light passing through it is equivalent approximately to an ionization loss of 1 BeV by a charged particle traversing the medium. Even though, say for a 100 BeV particle, a loss by the particle of 1% of its energy may not seem too serious a matter, the multiple scattering caused by a large chunk of matter would be serious for time of flight measurements. However, if we can select a dielectric medium which can be pumped separately to a metastable state which is very close to the ground state by either a low-energy laser light beam of a different frequency or by some other means, the simple passage of a charged particle can trigger and dump all the accumulated charges from the metastable state into the ground state. This dumping of the charges even in a small amount of material would be sufficient to cause a sudden change in the dielectric constant which in turn causes a shift in the laser phase that can be detected. A medium having such a property would be one that has a fine structure splitting of the metastable states. Perhaps a certain material can be artificially driven to produce fine-structure states such as by magnetic splitting, etc.

There may well be other more simple ways of triggering laser light pulses by a charged particle. Perhaps, the fact that a charged particle incident on a grating surface causes SPO may produce interaction with a laser light beam being reflected at such a surface. If there is sufficient interaction in the reflected laser beam to cause a change in its phase or other characteristics then this change can be detected and employed in the time of flight measurement. In any case further study on this matter would be extremely interesting and worthwhile.

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[5] Private Communications and discussions with Prof. William Bennett of Yale University and Dr. A. J. DeMaria of United Aircraft and Research Laboratory are most helpful and deeply appreciated.